Geologica Acta, Vol.6, Nº 2, June 2008, 147-160
DOI: 10.1344/105.000000248
Available online at www.geologica-acta.com

geologicaacta

An Early Ordovician (Floian) Conodont Fauna from the Eastern Cordillera of Peru (Central Andean Basin)

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ABSTRACT

Late Floian conodonts are recorded from a thin limestone lens intercalated in the lower part of the San José Formation at the Carcel Puncco section (Inambari River), Eastern Cordillera of Peru. The conodont association includes *Gothodus costulatus* LINDSTRÖM, *Protopanderodus rectus* (LINDSTRÖM), *Drepanoistodus basiovalis* (SERGEEVA), *Drepanoistodus forceps* (LINDSTRÖM), *Drepanodus arcuatus* PANDER, *Trapezognathus diprion* (LINDSTRÖM), *Erraticodon patu* COOPER, and *Ansella* cf. *jemtlandica* (LÖFGREN). This species association can be assigned to the upper part of the well-documented *Oepikodus evae* Zone. It is the northernmost conodont record of late Floian age in South America. This study updates the preliminary data presented in 2001 from this fossil locality, and it has important consequences for the paleogeographic reconstruction of the Peruvian part of the Central Andean Basin. In accordance with trilobites and brachiopods documented for the same strata, the conodont association represents a relatively cold-shallow-water platform environment. The record of late Floian conodonts towards the middle part of the San José Formation shows that the base of this unit in the studied section is considerably older than other sections of the distribution area, where its lowermost part is dated as early Darriwilian by the record of graptolites from the *Undulograptus austrodentatus* graptolite Zone. The diachronous initiation of the marine sedimentation makes the lower part of the Carcel Puncco shales penecontemporaneous with the volcanigenic rocks related with the Arequipa Massif, which transitionally underlie the San José Formation in other places of the Altiplano and the Eastern Cordillera of Peru.

KEYWORDS **Conodonts. Lower Ordovician. Paleogeography. Gondwana. Peru.**

INTRODUCTION

Reported Ordovician conodonts from the Andean basins are mainly from outcrops in Argentina. Important information on conodont faunas is now available from the Precordillera, Famatina, Eastern Cordillera and Puna geological provinces, as well as the Subandean Ranges (see the synthesis by Hünicken, 1989; Albanesi and Ortega, 2002; Albanesi et al., 2005, 2006; Ortega and Albanesi, 2005, and references therein). However, Ordovician conodonts are virtually unknown from the Central Andean Basin in Bolivia and Peru, from where scarce data on these microfossils and associated fauna were presented by Toro and Miranda (1991), Sarmiento et al. (2001), and Davies et al. (2007).

In this paper we review the information from the fossil locality in southeastern Peru reported by Sarmiento et al. (2001) on the basis of a re-study of the original collection described by these authors and a new conodont collection from the same bed and place. The Peruvian locality is of special interest in that it extends the known distribution of Ordovician conodonts into the western margin of Gondwana, and provides a better understanding of the distribution of the Baltoscandian Conodont Province on the shallow peri-Gondwanan shelves.

LOCATION AND STRATIGRAPHICAL SETTING

The fossiliferous locality is situated in the Carcel Puncco Canyon of the Inambari River near the Cuesta Blanca village, about 20 km northwest of the town San Gabán in the easternmost Eastern Cordillera of Peru (Fig. 1).

The general stratigraphy and age of the Ordovician succession, in this section, were established by Laubacher (1974), who described a lower shale unit, about 800 m thick, that was referred to the San José Formation (Fm), and an upper sandy and quartzitic unit, about 500 m thick, that was classified as the Sandia Fm. The first formation is now considered as Floian to Sandbian in age based on its significant paleontological record (Gutiérrez-Marco et al., 2004), whereas the second unit is tentatively assigned here to the Sandbian to Katian interval in the absence of diagnostic fossils. The Sandia Fm is overlain by glaciomarine shales and quartzites, which are correlated with the Hirnantian to Llandovery Zapla/Cancañiri Fm (locally known as San Gabán Fm: Pardo et al., 1973; Palacios et al., 1996; Cerpa et al., 2000; Díaz-Martínez, 2005; Díaz-Martínez and Grahn, 2007). In turn, it is overlain by a monotonous sequence of dark argillaceous shales belonging to the Ananea Fm of Middle Silurian to Devonian age.

The base of the San José Fm at Cuesta Blanca Village is truncated by the Quincemil or Subandean Fault (Fig. 1), which connects the Ordovician outcrops of the Eastern Cordillera that, in turn, overthrust the Cretaceous limestones and sandstones of the Subandean Zone.

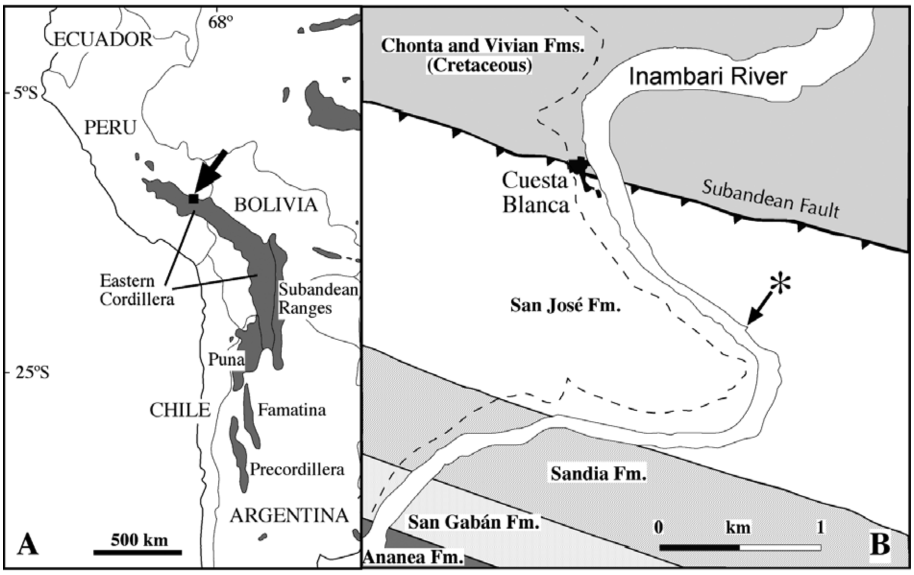


FIGURE 1 **A) Location of the study area in SE Peru, with reference to the Paleozoic outcrops of the Central Andean Basin (represented in black). B) Geological scheme of the Carcel Puncco canyon, adapted from the map of Palacios et al. (1996, Masuco Quadrangle) and Gutiérrez-Marco and Villas (2007). The arrow indicates the location of the Floian limestone lens (Sarmiento et al., 2001, and present work) that yielded the studied conodont elements.**

PALEONTOLOGY

The record of diverse Ordovician brachiopods, trilobites, molluscs, echinoderms, and graptolites of Arenig to Caradoc age from the same section of the San José Fm was published by Dávila and Ponce de León (1973), Laubacher (1974), Palacios et al. (1996), Gutiérrez-Marco et al. (2004), and Gutiérrez-Marco and Villas (2007).

About 95-100 m above the basal tectonic contact of the San José Fm, the fossiliferous shales exposed on the eastern bank of the Inambari River have an intercalation of a blue bioclastic limestone lens, which is ca. 3 m in length and has a maximum thickness of 30 cm. It has abundant brachiopods (*Paralenorthis immitatrix* HAVLÍCEK and BRANISA, and rare plectambonitoids), trilobites (*Neseuretus* sp., *Branisaspis* cf. *speciosa* PRIBYL and VANEK, *Ogyginus*? sp., and trinucleid fragments), rare euomphalacean gastropods, and some remains of ramose bryozoans and pelmatozoan columnals. This shelly fauna is comparable to that recorded from shales immediately below the limestone, where a single specimen of the graptolite *Tetragraptus quadribrachiatus* (HALL) was also collected.

A first account of the discovery of Early Ordovician conodonts in the previously mentioned limestone lens was presented by Sarmiento et al. (2001), who listed *Gothodus costulatus* LINDSTRÖM, *Drepanoistodus forceps* (LINDSTRÖM), *Protopanderodus rectus* (LINDSTRÖM), *Protopanderodus* cf. *robustus* (HADDING), *Baltoniodus* sp., *Erraticodon*? sp., *Drepanoistodus* sp., *Microzarkodina* sp. and *Periodon* sp. This conodont species association was interpreted to indicate an age close to the boundary between the Lower and Middle Ordovician Series.

MATERIAL AND PROCEDURE

A 800 g sample of the fossiliferous limestone from the San José Fm, which yielded the first Ordovician conodonts known from Peru, was studied in a preliminary way by Sarmiento et al. (2001). Recently, Gutiérrez-Marco and Villas (2007; Fig. 3) provided a detailed stratigraphic log for the lower part of this formation in the same section, which showed the exact location of the limestone lens (= their brachiopod horizon C), as indicated by a black star therein. A careful restudy of the conodont collection of Sarmiento et al. (2001) is here supplemented by data from a new sample of the same limestone (2200 g), which was dissolved by means of conventional acid etching techniques (Stone, 1987).

Stratigraphically higher in the Carcel Puncco section, i.e. at 11 m, 22 m and 200 m above the studied horizon, several samples from muddy limestone layers or calcareous nodules which are intercalated in the shale of the San José Fm, have been collected for the search of conodonts. Unfortunately, all these samples were barren. Sporadic occurrences of limestone in other Peruvian outcrops of the San José Fm are also known from the Altiplano region, northwest of the Titicaca lake (Rodríguez et al., 2000), as well as from the Eastern Cordillera in central Peru (Chacaltana et al., 2006; Díaz-Martínez et al., 2006). Both these occurrences are restricted to thin carbonate layers or resedimented blocks that occur in the lower part of the formation. They have not yet been studied for conodonts.

The conodont collection recovered from the 3 kg of limestone consists of 87 identifiable conodont elements and numerous undeterminable fragments. The conodont elements are black to grey, showing a CAI 5.5, which suggests overburden paleotemperatures over 300ºC for the bearer strata (Epstein et al., 1977).

CONODONT BIOSTRATIGRAPHY

The sampled limestone bed of the San José Fm yielded a conodont species association that represents the *Oepikodus evae* Zone in terms of the classic Baltoscandian biozonal scheme (Lindström, 1971; Löfgren, 1978). Lindström (1971) remarked that the lower part of the *O. evae* Zone is dominated by the nominal species while in the upper part this species is scarce or even absent. The conodont species are known from the upper part of the global Floian Stage of the Lower Ordovician Series (Slice Fl3 of Bergström et al., in press; also equivalent to the Time Slice 2c of Webby et al., 2004). The nominal species of the *O. evae* Zone is not present in our material, but the common ranges of the conodont species *D. forceps* (LINDSTRÖM), *Erraticodon patu* Cooper, *Gothodus costulatus* Lindström, and *Trapezognathus diprion* (LINDSTRÖM) clearly suggest correlation to the upper *Oepikodus evae* Zone sensu Lindström (1971). *G. costulatus* and *T. diprion* are significant taxa since their short ranges are restricted to the middle and upper part of the well-known *Oepikodus evae* Zone (Fig. 2).

The biozonal scheme for the Baltic region defined by Bagnoli and Stouge (1997) comprises the *O. evae*, *T. diprion*, and *Microzarkodina* sp. A biozones for same interval as the *O. evae* Zone *sensu* the original scheme (Sergeeva, 1964; Lindström, 1971). The conodont range chart published by Bagnoli and Stouge (1997) shows that the ranges of *G. costulatus* and *T. diprion* overlaps in the *T. diprion* Zone, i.e. in the upper *O. evae* Zone. *Oepikodus evae* is absent from the present assemblage and, accordingly, the species association from the San José Fm is assigned to the upper *O. evae* biozone or the correlative *T. diprion* biozone sensu Bagnoli and Stouge (1997). *Trapezognathus diprion* biozone represents the upper Billingenian Substage of the Latorp Stage, in the Lower Ordovician Series of the Baltoscandian regional standard chronostratigraphical scheme (Lindström, 1955, 1971; van Wamel, 1974; Löfgren, 1978, 1995; Bagnoli and Stouge, 1997; Viira et al., 2001).

New occurrences of *T. diprion* and *G. costulatus* in Argentina were recently recorded in preliminary studies by Heredia and Aceñolaza (2005) and Albanesi et al. (2006), respectively. The former species occurs in the Ordovician succession that crops out at Zenta Range, Eastern Cordillera of the Salta Province, Argentina, and the latter has been recorded from the San Juan Fm at Peña Sombría Creek in the northern Argentine Precordillera. Coeval species associations of conodonts with low diversity and high element abundance have been documented from the siliciclastic Cieneguillas and Acoite formations of Eastern Cordillera in NW Argentina (Rao et al., 1994), and the Suri Fm in the Famatina System; this latter unit representing a siliciclastic platform with volcanic influx (Albanesi and Astini, 2000).

Both *G. costulatus* and *T. diprion* have been recorded in the upper part of the *O. evae* Zone in the Huanghuachang section of south China (Wang et al., 2005), just below the first appearance datum of *Baltoniodus triangularis* (LINDSTRÖM), which was recently selected as a GSSP for the base of the Middle Ordovician Series. Incidentally, the conodont ranges of the species in common with the San José Fm in Peru are constrained to be within the upper part of the Floian Stage of the Lower Ordovician Series (Stage Slice Fl3 of Bergström et al., in press).

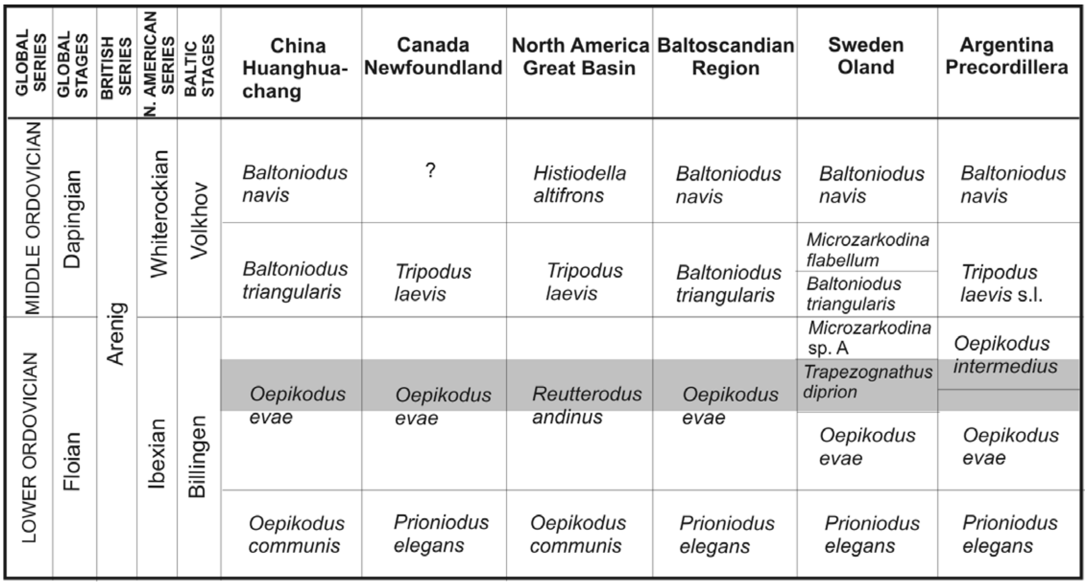
PALEOENVIRONMENTAL AND PALEOBIOGEOGRAPHICAL CONSTRAINS

Conodonts

The conodont association is dominated by *Gothodus* (70%), whereas *Drepanoistodus* (9%), *Protopanderodus* (7%), *Drepanodus* (< 5%), *Trapezognathus* (< 5%), and *Erraticodon* (< 4 %) are moderate, and *Ansella* is less abundant (about 1%).

The conodont genera from the studied level of the San José formation, particularly *Drepanodus, Drepanoistodus, Gothodus, Protopanderodus*, and *Trapezognathus,* are pandemic forms. The genus *Ansella,* though not restricted to, is more typical of the Baltoscandian region. The presence of *Erraticodon* could be explained as a migrational event from warmer regions onto the South American-Gondwanan platform during the *O. evae* highstand (Nielsen, 2004; Albanesi and Bergström, 2004).

Our conodont collection lacks characteristic taxa that became extinct in the interval that spans the latest Floian (e.g., *Bergstroemognathus, Reutterodus, Tropodus*) to earliest Dapingian stages, as well as the absence of new taxa, which appear for the first time (e.g., *Cooperignathus,*



GLOBAL SERIES	GLOBAL STAGES	BRITISH SERIES	N. AMERICAN SERIES	BALTIC STAGES	China Huanghua-chang	Canada Newfoundland	North America Great Basin	Baltoscandian Region	Sweden Oland	Argentina Precordillera
MIDDLE ORDOVICIAN	Dapingian	Arenig	Whiterockian	Volkhov	*Baltoniodus navis*	?	*Histiodella altifrons*	*Baltoniodus navis*	*Baltoniodus navis*	*Baltoniodus navis*
					Baltoniodus triangularis	*Tripodus laevis*	*Tripodus laevis*	*Baltoniodus triangularis*	*Microzarkodina flabellum*	*Tripodus laevis* s.l.
									Baltoniodus triangularis	
LOWER ORDOVICIAN	Floian		Ibexian	Billingen					*Microzarkodina* sp. A	*Oepikodus intermedius*
					Oepikodus evae	*Oepikodus evae*	*Reutterodus andinus*	*Oepikodus evae*	*Trapezognathus diprion*	
									Oepikodus evae	*Oepikodus evae*
					Oepikodus communis	*Prioniodus elegans*	*Oepikodus communis*	*Prioniodus elegans*	*Prioniodus elegans*	*Prioniodus elegans*

FIGURE 2 | **Biostratigraphic correlation chart. The shadow interval corresponds to the chronostratigraphic range of the conodont association recorded from the San José Formation (chart modified after Albanesi et al., 2006).**

Microzarkodina, Tripodus) in the same interval within tropical domains. This diversity pattern is characteristic for temperate to cold-water settings (Albanesi and Bergström, 2004).

Following the conodont biogeographic hierarchy proposed by Zhen and Percival (2003) for the Lower Ordovician, the studied conodont assemblage is similar to that contemporaneous of the Baltoscandian Province from the Shallow-Sea Realm, *i.e.,* a cold-water domain with low diversity and relatively high specimen abundance conodont fauna, or faunas of the cold-temperate water North Atlantic Realm or the Atlantic Faunal Region of previous classifications (Bergström, 1990; Pohler and Barnes, 1990; Rasmussen, 1998, among others). Notwithstanding that, our conodont collection is not as high in number of specimens as those from the Baltoscandian carbonate platform, probably because of higher sedimentary rates and particular environments in the siliciclastic shelf of South-American Gondwana. Disregarding differences in the sedimentary settings of these basins, the proposed conodont realm apparently extends along the shallow-water (< 200 m depth) shelf, as a new province of the South-American Gondwanan margin, including the Eastern Cordillera of Peru, Bolivia, and Argentina.

This paleobiogeographic unit has been recently recognized by Albanesi et al. (2007) for the *Paltodus deltifer* Zone (late Tremadocian) in the Eastern Cordillera of northwestern Argentina. The composition of this conodont assemblage demonstrates a unique faunal distribution pattern, with a faunal interplay across the Iapetus Ocean, suggesting that it may be appropriate to distinguish a new conodont paleobiogeographic unit for the Early Ordovician in the Gondwanan margin; *i.e.*, the South Gondwana Province of the Cold Domain in the Shallow-Sea Realm, following Albanesi et al. (2007). The studied late Floian conodont collection from Peru apparently verifies the occurrence of this province for a major part of the Early Ordovician.

Brachiopods and trilobites

Similar paleoenvironmental and paleobiogeographic relationships are shown by the macrofossils that are associated with the conodonts from the productive limestone, or are recorded from the under- and overlying shale. Some identified brachiopods and trilobites (e.g., *Paralenorthis immitatrix*, *Ahtiella*, *Neseuretus*, *Branisaspis* speciosa) are also present in correlative strata in the Central Andean Basin from southern Bolivia and northern Argentina (Gutiérrez-Marco et al., 2004; Gutiérrez-Marco and Villas, 2007). The record of *Neseuretus* in the Carcel Puncco section is particularly interesting because this genus typifies a widespread trilobite association found from clastic facies of the shallow-water shelf, which extended almost all the way around Gondwana and outside the paleoequatorial belt (Fortey and Morris, 1982; Turvey, 2002; Fortey and Cocks, 2003). The limestone deposition could have been favored by having taken place in temperate seawaters as suggested by the occurrence of typical brachiopods, such as the genus *Ahtiella,* which have been reported from these strata by Gutiérrez-Marco and Villas (2007). *Neseuretus* and *Ahtiella* are also present in the Famatina System in northwestern Argentina, where they are associated with a conodont fauna that is coeval with that of the present study. These communities were tolerant to the restricted environmental conditions that prevailed on the siliciclastic and volcaniclastic platform of the Suri Fm (Albanesi and Vaccari, 1994; Vaccari and Waisfeld, 1994; Benedetto, 2003).

DISCUSSION

The interpretation that relatively shallow-water depositional environment prevailed in the Carcel Puncco section as indicated by the conodont and shelly faunas recorded from the lower part of the San José Fm is opposing previous interpretations of a depositional environment for this formation. Both Martínez and Monge (2000) and Reinmann et al. (2006) suggested that deeper offshore environments characterized the deposition of the San José Fm everywhere. In contrast to this and in our opinion, low-energy deep-water conditions only dominated the deposition of the San José Fm from the earliest Darriwilian (*Undulograptus austrodentatus* graptolite Zone), where a thick succession of black-shale intercalated with fine-grained turbidites is described. The Darriwilian strata bear epi- and mesopelagic graptolites and olenid trilobites that probably reflect a particular episode of sea-level rise (Reimann et al., 2006).

The late Floian conodonts from the lower part of the San José Fm provide the so far oldest biostratigraphic dating in the Ordovician of Peru. The age significance of other identified Early Ordovician fossils previously documented for the San José and Sandia formations is highly questionable because it was only estimated from reworked fossils, as indicated in the general review by Gutiérrez-Marco et al. (2004) and by unpublished field data of the senior author, respectively. The Floian age for the lower part of the San José Fm in the study area indicates a highly diachronic lower boundary of the formation. It is partly coeval with the backarc volcanic and volcaniclastic rocks exposed in the Eastern Cordillera and the Altiplano region of Peru, namely the Ollantaytambo Fm and Umachiri beds, respectively (Bahlburg et al., 2006). The upper part of both these units grades conformably in their stratotype areas into the overlying marine and non-volcanigenic San José Fm, the basal part of which locally includes graptolite shales not older than the Darriwilian (Reimann et al., 2006; Spiske et al., 2006). Therefore, the relatively shallow open-shelf facies of the basal San José Fm in the Carcel Puncco section is penecontemporaneous with the volcaniclastic sediments, or with the conglomerates of the Verónica Fm, which locally cuts unconformably the Ollantaytambo Fm in restricted areas of the Eastern Cordillera. Our data enhance the complexity of the pre-Darriwilian paleogeographic setting envisioned by Bahlburg et al. (2006), in which the lapilli tuffs and clastic material of the formations just mentioned were derived from isolated mafic to intermediate volcanic centers, which in turn were connected to a westward-lying magmatic arc on the Arequipa Massif and surrounded by normal marine open-shelf environments in a backarc basin (Ramos, 2008).

The claimed paleogeographic scenario for the northern part of the Central Andean Basin also explains why a local shallow-water setting around the volcanic arc prevailed during the late Floian, when normally the *O. evae* Zone coincides with a large highstand interval (Time Slice Fl3) almost everywhere (Albanesi and Bergström, 2004).

SYSTEMATIC PALEONTOLOGY

The taxonomy of conodonts follows the most recent concepts on multielement apparatuses as used by cited authors, who provided latest revisions of each identified species. The synonymy list includes the original reference of each species, selected references for their complete description and discussion (all of them with more complete synonymies), and the local synonymy of the Peruvian specimens as previously identified by Sarmiento et al. (2001). In order to note these previously identified elements, the specific signs used before the year in the synonymy list follows those provided by Matthews (1973).

The conodont material is housed with the micropaleontological collection of the Museum of the Geological Survey of Spain (Museo Geominero, Instituto Geológico y Minero de España, Madrid), under code MGM.

GENUS ***Ansella*** FÅHRAEUS and HUNTER, 1985

Type species: *Belodella jemtlandica* LÖFGREN, 1978

Ansella* cf. *jemtlandica (LÖFGREN, 1978)
Figure 3.4

cf. 1978 *Belodella jemtlandica* LÖFGREN, pp. 46–49, pl. 15, figs. 1–8, figs. 24 A–D
cf. 1984 *Belodella jemtlandica* LÖFGREN; STOUGE, p. 60, pl. 6, figs. 13-23; pl. 7, figs. 1-4.
cf. 1985 *Ansella jemtlandica* (LÖFGREN); FÅHRAEUS and HUNTER, pp. 1173–1175, pl. 1, figs. 1–5, 9, pl. 2, figs. 12a–b, Fig. 1.
cf. 1998 *Ansella jemtlandica* (LÖFGREN); ALBANESI, pp. 160–161, pl. 1, figs. 18–23; text-fig. 27.
v. 2001 *Microzarkodina* sp.; SARMIENTO et al., p. 538.
cf. 2001 *Ansella jemtlandica* (LÖFGREN); RASMUSSEN, pp. 51–53, pl. 1, figs 4–9.

Remarks: A geniculate oistodiform element typical of the genus *Ansella* is recorded. Anagenetic developments of the *Ansella* complex are recorded through its apparently extensive chronostratigraphic range, from the *Prioniodus elegans* Zone up to the *Lenodus variabilis* Zone as recorded by Albanesi (1998). Despite the morphology of the oistodiform (M) element of our collection is similar to that one originally described by Löfgren (1978), the only element recorded here precludes further identification.

Material: 1 M

Repository: MGM-6205-X

GENUS ***Drepanodus*** PANDER, 1856

Type species: *Drepanodus arcuatus* PANDER, 1856

Drepanodus arcuatus PANDER, 1856
Figures 3.19, 3.20

1856 *Drepanodus arcuatus* PANDER, p. 20, pl. 1, figs. 2, 4, 5, 17, 30, ?31
2003 *Drepanodus arcuatus* PANDER; LÖFGREN and TOLMACHEVA, pp. 211–215, figs. 2, 3A–C, E–H, 5K–V, 6M–U, 7H–N, 8A–G.

Remarks: The species apparatus has been recently described and discussed by Löfgren and Tolmacheva (2003). These authors provide a thorough review of the taxonomy of *Drepanodus arcuatus*, including a complete synonymy list, differences to other species, and discuss its wide geographic distribution and paleoecology. The newly reconstructed conodont apparatus incorporates all morphotypes previously identified by Dzik (1994), although a different location of each form is suggested. The morphologies of elements in our collection fully agree with the descriptions given by Löfgren and Tolmacheva (2003).

Material: 1 P, 1 M, 1 Sb, 1 Sc.

Repository: MGM-6220, 6221, 6234 and 6235-X

GENUS ***Drepanoistodus*** LINDSTRÖM, 1971

Type species: *Oistodus forceps* LINDSTRÖM, 1955

Drepanoistodus basiovalis (SERGEEVA, 1963)
Figures 3.29–3.31

1963 *Oistodus basiovalis* SERGEEVA, p. 96, pl. 7, figs. 6-7, text-fig. 3.
P 1978 *Drepanoistodus basiovalis* (SERGEEVA); LÖFGREN, pp. 55–56, pl. 1, figs. 11–12, 13–16 (only).
2001 *Drepanoistodus basiovalis* (SERGEEVA); RASMUSSEN, pp. 71–73, pl. 5, fig. 9.
?2001 *Drepanoistodus* sp.; SARMIENTO et al., p. 538 , pl. 1, fig. 2.
2007 *Drepanoistodus basiovalis* (SERGEEVA); ZHEN et al., pl. 1, figs. 27–37.

Remarks: *Drepanoistodus basiovalis* is a common and well described species in the Baltoscandian region, although it is a widespread species, known in China, North and South America as well. It was derived from *D. forceps* according to the recent interpretation of Löfgren (2005). The lineage involves a complex of intraspecific forms that were labelled *D.* cf. *basiovalis* and *D.* aff. *basiovalis* (see discussions by Stouge and Bagnoli, 1990, and Rasmussen, 2001). These are of almost identical shape, but are distinguished by the relation of the length between cusp and base of the oistodiform elements. The relationships between similar forms of *Drepanoistodus* were also discussed by Zhen et al. (2007), who illustrated *D. forceps* and *D. basiovalis* in detail. The species determined as *Drepanoistodus basiovalis* by Lehnert (1995) and Albanesi (1998) probably belongs to *D.* cf. *basiovalis*. Specimens of our collection are typical representatives of *D. basiovalis* and their morphologies agree with the descriptions by previous authors.

Material: 1 M, 1 ?Sa, 1 Sb, 1 Sc

Repository: MGM-6230-X to MGM-6233-X

Drepanoistodus forceps (LINDSTRÖM, 1955)
Figures 3.26–3.28

1955 *Oistodus forceps* LINDSTRÖM, pp. 74–75, pl. 6, figs. 1–6.
1971 *Drepanoistodus forceps* (LINDSTRÖM); LINDSTRÖM, p. 42, figs. 5, 8.
1998 *Drepanoistodus forceps* (LINDSTRÖM); ALBANESI, p. 136, pl. 3, figs. 19–22.
2001 *Drepanoistodus forceps* (LINDSTRÖM); RASMUSSEN, pp. 74–75, pl. 6, figs. 1–6.
v. 2001 *Drepanoistodus forceps* (LINDSTRÖM); SARMIENTO et al., pp. 537–538.
p. 2002 *Drepanoistodus forceps* (LINDSTRÖM); PYLE and BARNES, p. 63, pl. 19, figs. 11–12 (non 10).
2007 *Drepanoistodus forceps* (LINDSTRÖM); ZHEN et al., pp. 130–132, pl. 1, figs. 1–16.

Remarks: Various authors (e.g., Löfgren, 1978; Dzik, 1994; Albanesi, 1998; Rasmussen, 2001; Zhen et al., 2007) described the characteristics of the species apparatus, which was first reconstructed by Lindström (1971), as well as the differences to other similar forms. Löfgren (2005) described the apparatus architecture of the genus *Venoistodus*, which includes oistodiform elements that have been confused frequently with the homologous elements of its ancestor *Drepanoistodus forceps*. The element figured by Pyle and Barnes (2002) as M of *D. forceps* may belong to the M element of *Paroistodus originalis* (Sergeeva).

Material: 2 M, 1 Sb, 1 Sc

Repository: MGM-6227 to 6229-X, MGM-6236-X

GENUS ***Erraticodon*** DZIK, 1978

Type species: *Erraticodon balticus* DZIK, 1978

Erraticodon patu COOPER, 1981
Figures 3.1–3.3

1981 *Erraticodon patu* COOPER, p. 166, pl. 32, figs. 1–6, 8.
1990 *Erraticodon patu* COOPER; NICOLL, fig. 2.1.
1994 *Erraticodon patu* COOPER; ALBANESI and VACCARI, p. 137, pl. 1, figs. 11–16.
p. 1995 *Erraticodon patu* COOPEr; LEHNERT, p. 88, pl. 10, fig. 11.
v. 2001 *Plectodina?* sp.; SARMIENTO et al., p. 538.
v. 2001 *Erraticodon?* sp.; SARMIENTO et al., pl. 1, fig. 1.
2003 *Erraticodon patu* COOPER; ZHEN et al., pp. 195–198, figs. 16A–K, 17A–O.
2004 *Erraticodon patu* COOPER; NICOLL and KELMAN, pp. 209–218, figs. 2–8.

Remarks: *Erraticodon patu* includes a septimembrate apparatus with Pa, Pb, M, Sa, Sb, Sc, and Sd morphotypes. After the original description by Cooper (1981), all these element morphotypes were described in detail by Nicoll and Kelman (2004) and Zhen et al. (2003) based on Australian specimens. Three elements were recovered from the San José Fm, whose morphologies fully agree with the descriptions by mentioned authors of the corresponding M, Sa, and Sd elements. These authors discussed the differences between *E. patu* and other species of the lineage, such as *E. balticus* Dzik, 1978, and *E. tangshanensis* Yang and Xu (in An et al., 1983). Apparently, there are subtle differences between specimens from different study areas, for example, between those from the Famatina System in Argentina (Albanesi and Vaccari, 1994) and Australia (Zhen et al., 2003); however, these could be of ecophenotypic type and reflect adaptation to diverse environments (carbonate and siliciclastic platforms or basins with volcanic influxes) that this species was able to colonize.

Material: 1 M, 1 Sa, 1 Sd

Repository: MGM-6202 to 6204-X

GENUS ***Gothodus*** LINDSTRÖM, 1955

Type species: *Gothodus costulatus* LINDSTRÖM, 1955

Remarks: Bagnoli and Stouge (1997) have emended the diagnosis of the genus *Gothodus* LINDSTRÖM. They discuss all previous papers that dealt with this genus, where it had been confused with *Prioniodus* PANDER, *Baltoniodus* LINDSTRÖM, and *Oepikodus* LINDSTRÖM. Bagnoli and Stouge (1997) remark that *Gothodus* is phylogenetically independent from *Prioniodus* and *Baltoniodus*, and represents a distinct genus of early Arenig–late Llanvirn age, and they suggest a possible relationship between *Gothodus* and the derived genus *Phragmodus*. A thorough revision of the latter genus was offered by Leslie and Bergström (1995).

Gothodus costulatus LINDSTRÖM, 1955
Figures 3.5–3.14

1955 *Gothodus costulatus* LINDSTRÖM, p. 569, pl. 5, figs. 23–25.
p. 1971 *Gothodus costulatus* LINDSTRÖM; LINDSTRÖM, p. 54–55 (partim), pl. 1, figs. 4, 5 (only).
1988 *Baltoniodus crassulus* (LINDSTRÖM); BAGNOLI et al., p. 208, pl. 38, figs. 1–7.
1997 *Gothodus costulatus* LINDSTRÖM; BAGNOLI and STOUGE, p. 140–141, pl. 2, figs. 10–17.
v. 2001 *Gothodus costulatus* LINDSTRÖM; SARMIENTO et al., p. 537, pl. 1, fig. 3.
?v. 2001 *Periodon* sp.; SARMIENTO et al., p. 538.
?v. 2001 *Erismodus*? sp.; SARMIENTO et al., p. 538.

Discussion: The apparatus of *Gothodus costulatus* includes 7 morphotypes, namely Pa and Pb pectiniform elements (pastinate), and a symmetry transition series formed by Sa (alate), Sb (tertiopedate), Sc (bipennate), and Sd (quadriramate) ramiform elements. All these morphotypes were described in detail by Bagnoli and Stouge (1997). The elements of our collection are identical in appearance to those described by the cited authors from the Lower Ordovician of Öland, Sweden.

Remarks: In a recent contribution by Albanesi (2006), this author showed that a lineage of *Gothodus* evolved in the South American margin of Gondwana. *Gothodus costulatus,* is known from the middle *Oepikodus evae* Zone in open platform facies of the San Jose Fm in the Peruvian Eastern Cordillera, and is also reported in distal facies of the San Juan Fm in the Argentine Precordillera. This species would be the ancestral form of *Baltoniodus crassulus andinus* Rao et al., 1994, which occurs in the upper part of the *Oepikodus evae* Zone. It was recorded in the siliciclastic Acoite and Cieneguillas formations at the Eastern Cordillera of Jujuy, as well as in the volcaniclastic Suri Fm in the Famatina System, La Rioja and Catamarca provinces, northwestern Argentina (Albanesi and Astini, 2000). It should also be noted that the P elements of *B. crassulus andinus* (which were referred to as *Gothodus* n. sp. A by Albanesi 2006) developed denticles along the lateral processes as an apomorphic character. The denticles of other morphotypes appear taller although they are still fused at their basal parts. The basal sheath is slightly less developed than in *G. costulatus*. This species seems to be the ancestor of *Gothodus* n. sp. B of Albanesi, 2006, which occurs in distal ramp facies, across the San Juan–Gualcamayo formation boundary (uppermost Floian) in the northern Precordillera of Argentina (Albanesi et al., 2006). This new species is characterized by having completely denticulated processes of the P elements, shorter basal sheaths, and wider angles between the anterior and lateral processes. Denticles of all elements are discrete, triangular in lateral view, and irregular in height in relation to the distal part of the processes. These derived species from the ancestral *G. costulatus* are apparently endemic to the South American margin of Gondwana and the Argentine Precordillera. Although other similar forms are present in south China (Wang et al.,

FIGURE 3 | **Late Floian conodonts from the studied locality. 1-3) *Erraticodon patu* COOPER, 1981. 1, Sa element, MGM-6202-X; 2, Sb element, MGM-6203-X; 3, M element, MGM-6204-X. 4) *Ansella* cf. *jemtlandica* (LÖFGREN, 1978). M element, MGM-6205-X. 5-14) *Gothodus costulatus* LINDSTRÖM, 1955. 5, Pa element, MGM-6206-X; 6, Pb element, MGM-6207-X; 7–9, M elements, MGM-6208 to 6210-X; 10,12, Sd elements, MGM-6211 and 6213-X; 11, Sa element, MGM-6212-X; 13, Sb element, MGM-6214-X; 14 Sc element, MGM-6215-X. 15–18) *Trapezognathus diprion* (LINDSTRÖM, 1955). 15-16, Sd elements, MGM-6216 and 6217-X; 17, Sb element MGM-6218-X; 18, Sa element, MGM-6219-X. 19–20) *Drepanodus arcuatus* PANDER, 1856. 19, Sc element, MGM-6220-X; 20, P element, MGM-6221-X. 21-25) *Protopanderodus rectus* LINDSTRÖM, 1955. 21, P element, MGM-6222-X; 22, 25, Sc elements, MGM-6223 and 6226-X; 23, Sa element, MGM-6224-X; 24 Sb element, MGM-6225-X. 26-28) *Drepanoistodus forceps* LINDSTRÖM, 1955. 26, M element, MGM-6227-X; 27, Sb element, MGM-6228-X; 28, P element, MGM-6229-X. 29–31) *Drepanoistodus basiovalis* (SERGEEVA, 1963). 29, Sc element, MGM-6230-X; 30, M element, MGM-6231-X; 31, ?Sa element, MGM-6232-X. All figures are SEM micrographs.**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2005), the Baltoscandian region, Nevada and California deep-water settings, where they dominate the faunas together with common species of *Protopanderodus* and *Periodon* (Stouge, pers. comm., 2008).

Material: 3 Pa, 4 Pb, 8 Sa, 11 Sb, 13 Sc, 17 Sd, 5 M

Repository: MGM-6206 to 6215-X, MGM-6237 to 6287-X

GENUS ***Protopanderodus*** Lindström, 1971

Type species: *Acontiodus rectus* Lindström, 1955

Protopanderodus rectus (Lindström, 1955)
Figures 3.21–3.25

1955 *Acontiodus rectus* Lindström, p. 549, pl. 2, 7–11, text-figs. 2k–m, 3b.
1994 *Protopanderodus rectus* (Lindström); Dzik, pp. 72–73, pl. 13, 27–30, text-fig. 10a.
1998 *Protopanderodus rectus* (Lindström); Albanesi, p. 129, pl. 11, figs. 9–12, text-fig. 14c.
2001 *Protopanderodus rectus* (Lindström); Rasmussen, pp. 124–125, pl. 16, figs. 1–4.
v. 2001 *Protopanderodus rectus* (Lindström); Sarmiento et al., p. 538.
v. 2001 *Protopanderodus* cf. *robustus* (Hadding); Sarmiento et al., p. 538.
?p. 2002 *Protopanderodus leonardii* Serpagli; Pyle and Barnes, p. 60, pl. 27, figs. 5 and 7 (only).
?2002 *Protopanderodus rectus* (Lindström); Pyle and Barnes, p. 60, pl. 27, fig. 8.
2006 *Protopanderodus rectus* (Lindström); Mellgren and Eriksson, pp. 102–104, figs. 8 and 9A–G.

Remarks: *Protopanderodus rectus* has been described by Löfgren (1978), and the species apparatus reconstructed by Dzik (1994) includes four morphotypes (see McCracken, 1989); however, a more complex architecture expected for this genus following recent reconstructions of related coniform taxa of the Protopanderodontidae (e.g., the apparatus reconstruction of *Drepanodus* by Löfgren and Tolmacheva, 2003, that includes seven morphotypes), was recently verified in a comprehensive study for Baltoscandian species by Mellgren and Eriksson (2006). The authors proposed an apparatus that consists of M, Sa, Sb1, Sb2, Sc, Pa and Pb elements for *P. rectus*. A similar number of element types was identified for other bicostate species of the genus, conversely to the multicostate complex, whose apparatus architecture includes nine different morphotypes, following these authors. The small size of our small collection precludes further interpretation. The species is common in the Baltoscandian region and the Holy Cross Mountains in Poland, and some intraspecific differences within the *Protopanderodus rectus* complex have been observed by Rasmussen (2001). This species has been also recorded in more distant areas, such as the Argentine Precordillera (Albanesi, 1998) and northeastern British Columbia, Canada (Pyle and Barnes, 2002), which demonstrates its wide geographic distribution (see Mellgren and Eriksson, 2006, for full references).

Material: 1 P, 1 Sa, 2 Sb, 2 Sc

Repository: MGM-6222 to 6225-X, MGM-6288-X

GENUS ***Trapezognathus*** Lindström, 1955

Type species: *Trapezognathus quadrangulum* Lindström, 1955

Trapezognathus diprion (Lindström, 1955)
Figures 3.15–3.18

1955 *Prioniodina diprion* Lindström, p. 587, pl. 5, fig. 43.
1997 *Trapezognathus diprion* (Lindström); Bagnoli and Stouge, pp. 159–160, pl. 7, figs. 1–8.
v. 2001 *Baltoniodus* sp.; Sarmiento et al., p. 538.

Remarks: The diagnosis of *Trapezognathus diprion* was emended by Bagnoli and Stouge (1997), who provided a full description of the seven morphotypes that compose the species apparatus. The morphologies of the Sa, Sb, Sc, and Sd elements in our collection agree in detail with the descriptions provided by the latter authors. The morphology of the S element is typical of *Trapezognathus*, and it is one of diagnostic elements of the apparatus. The Sd element present in our collection allows for the species identification. It is characterized by long processes with incipient denticles, which are connected by a basal sheath, and the tip of the cusp is blunt. S elements of *T. quadrangulum* Lindström, the derived species, are characterized by slightly longer processes and well developed denticulation.

Material: 1 Sa, 1 Sb, 1 Sc, 1 Sd

Repository: MGM-6216 to 6219-X

CONCLUSIONS

The conodont fauna recovered from a calcareous lens within the lower half of the San José Fm is fully described on the basis of new samples. The fossil assemblage is referred to the upper part of the *Oepikodus evae* Zone (late Floian). The present biostratigraphical reappraisal constrains the age range of the conodont-bearing deposit, which had previously been assigned a late Early to early Middle Ordovician age by Sarmiento et al. (2001).

The conodont fauna represents a shallow cold-water domain with low species diversity and relatively high specimen abundance. Similar conodont faunas have previously been recorded in several formations in the Central Andean Basin, as well as in the Famatina System of Argentina, characterizing a South Gondwana Province of the Cold Domain in the Shallow-Sea Realm.

The Floian age for the lower half of the San José Fm in the study area indicates a highly diachronic lower boundary of the formation, because in the remaining sections of the Eastern Cordillera, the sedimentation of the same unit commenced in the early Darriwilian (within the *Undulograptus austrodentatus* graptolite Zone). Therefore, the basal part of the San José Fm in the Carcel Puncco section is penecontemporaneous with the Early Ordovician arc-related volcanic rocks recorded near Cuzco (Ollantaytambo Fm) and in the Altiplano (Umachiri Beds), which are paleogeographically connected to the Arequipa Massif.

The present record represents the third locality with conodonts known from Peru, where these microfossils have been previously reported only from late Triassic strata (Maeda et al., 1984; Orchard, 1994). Likewise, our locality represents one of the two known occurrences of Ordovician conodonts in northern South America, following the recent discovery of Lower and Middle Ordovician faunas in Colombia (Gutiérrez-Marco et al., 2007).

ACKNOWLEDGEMENTS

This research work has been funded by the AECI (Spanish Agency for International Cooperation) and the Research Group on Perigondwanan Precambrian and Paleozoic of the Universidad Complutense (Madrid, Spain). José Cárdenas (Universidad Nacional San Antonio Abad, Cuzco, Peru) and Dr. Enrique Díaz Martínez (Spanish Geological Survey-IGME, Madrid) are thanked for valuable assistance during the expeditions of 2002 and 2004. Guillermo L. Albanesi thanks especially the CONICET and ANPCyT (FONCyT), Argentina, for continuous support of his conodont studies. The referees of this paper, Svend Stouge (Copenhagen, Denmark), Stig M. Bergström (Columbus, Ohio, USA), and Yong Yi Zhen (Sydney, Australia), are greatly acknowledged for their recommendations in order to improve the final version. This paper is a contribution to the IGCP project 503.

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Manuscript received January 2008;
revision accepted May 2008;